Coquillages, matériaux innovants et changement climatique

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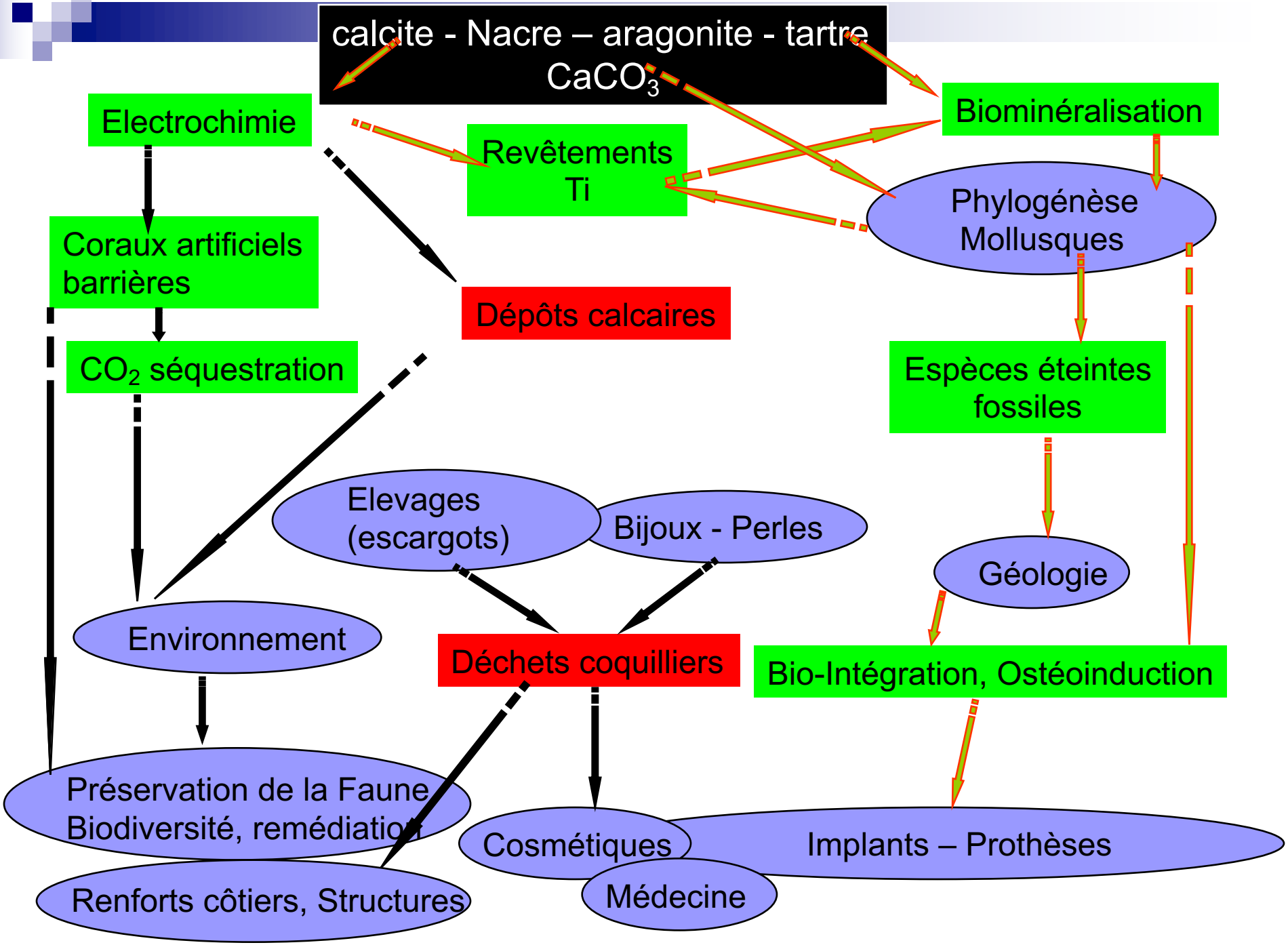
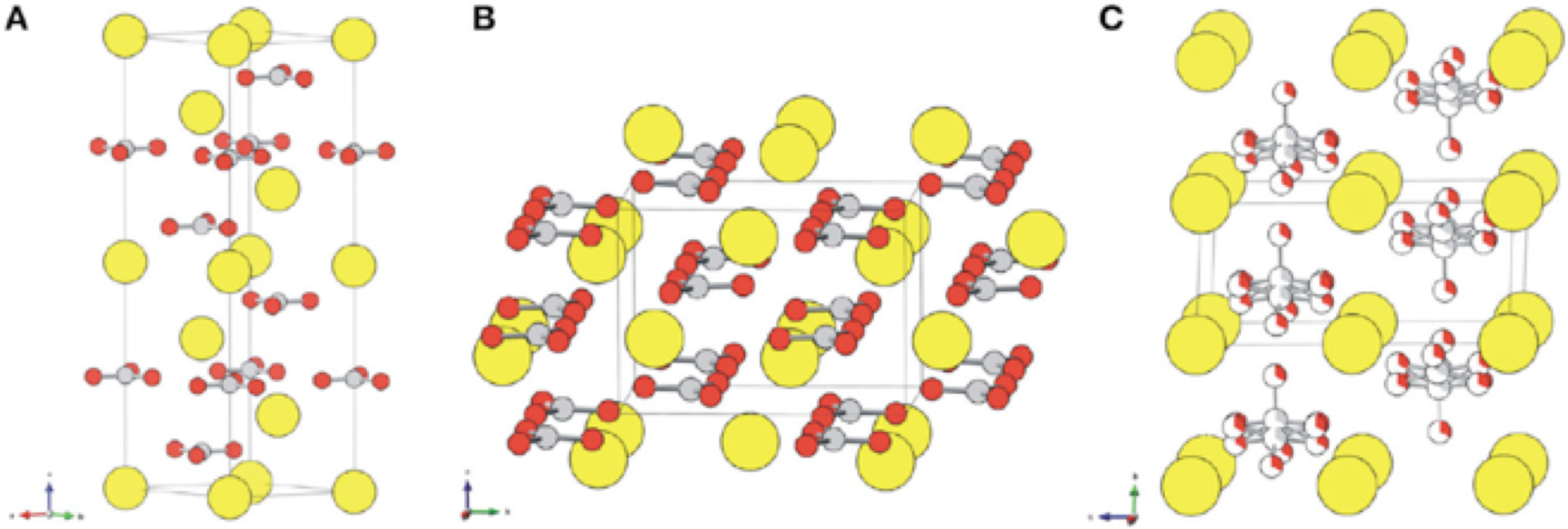
Coquillages, les 1000 vies du coquillage, 29 Sept. 2021, Sainte-Marie-de-Ré


calcite - Nacre – aragonite - tartre
$CaCO_3$
Electrochimie
Biominéralisation
Revêtements
Ti
Phylogénèse
Mollusques
Coraux artificiels
barrières
Dépôts calcaires
CO_2 séquestration
Espèces éteintes
fossiles
Elevages
(escargots)
Bijoux - Perles
Géologie
Environnement
Déchets coquilliers
Bio-Intégration, Ostéoinduction
Préservation de la Faune
Biodiversité, remédiation
Cosmétiques
Implants – Prothèses
Médecine
Renforts côtiers, Structures



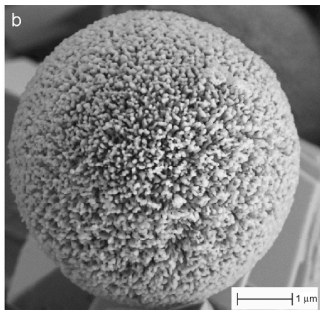
Calcite Aragonite Vaterite

Aplanarité des groupements carbonate dans $CaCO_3$:

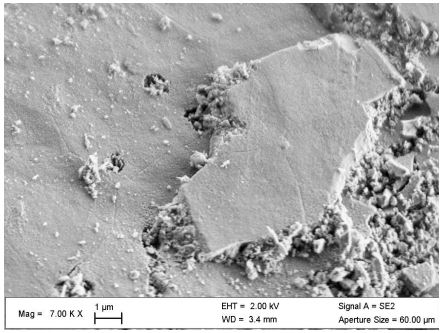
$$\Delta Z_{C\text{-}O1} = c(z_C - z_{O1})$$

T, pH

Minéral

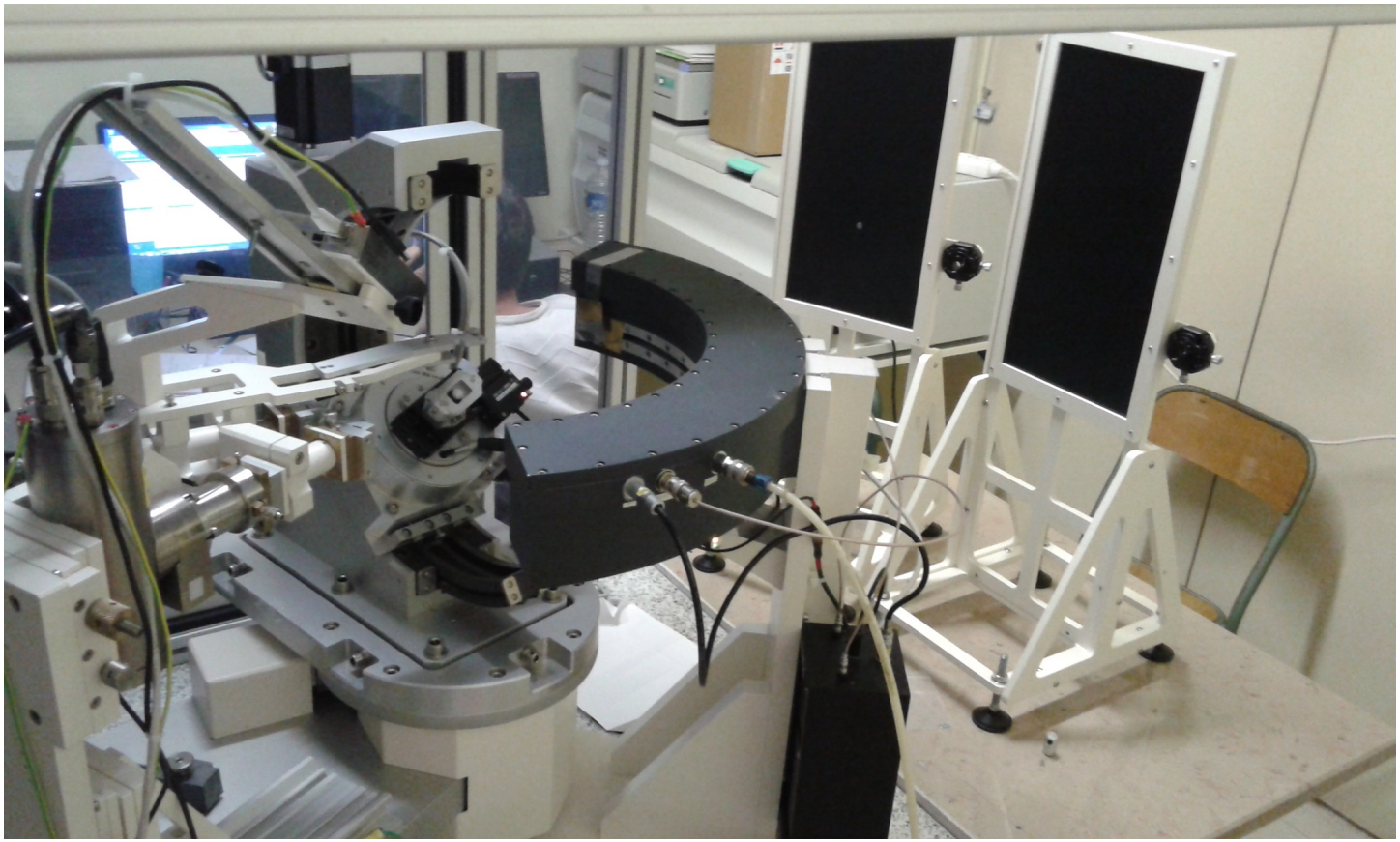
calcite	aragonite	vaterite
0 Å	0.05744 Å +2 kJ/mol	

Biogénic

calcite	*aragonite*	*vaterite*
	CO_3 plus distordu	

[Mg2+], molécules inter/intracrystalline

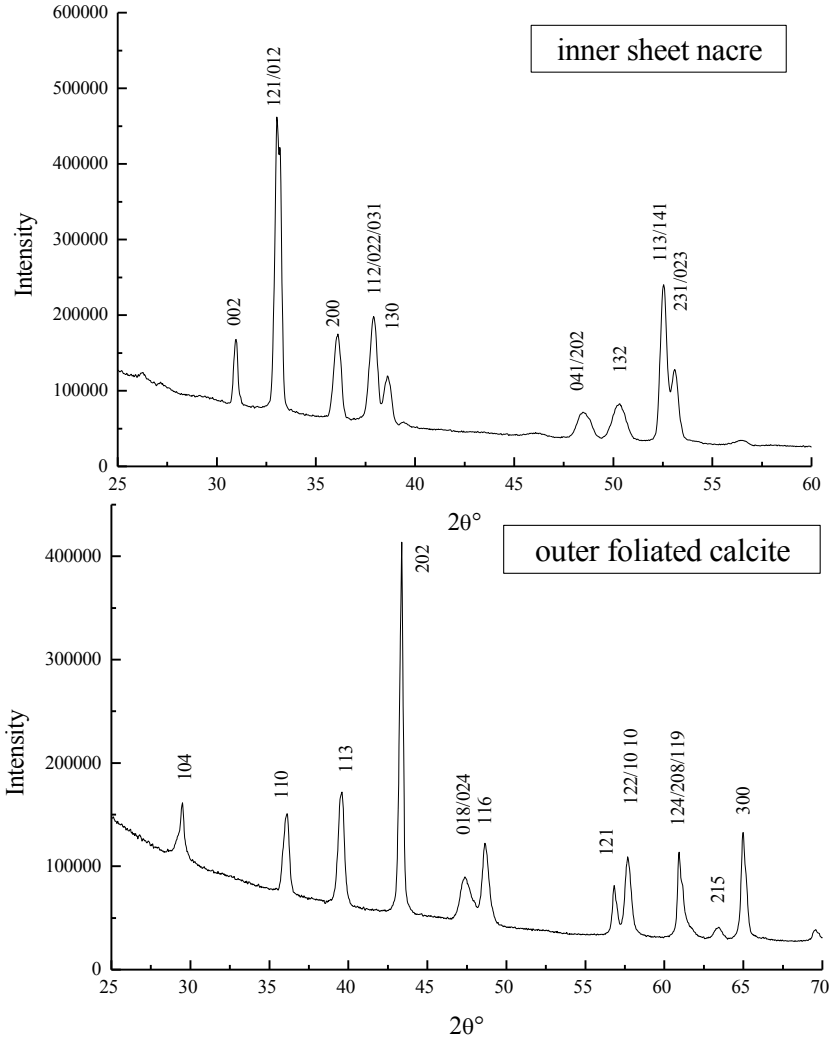
Une expérience type de diffraction X



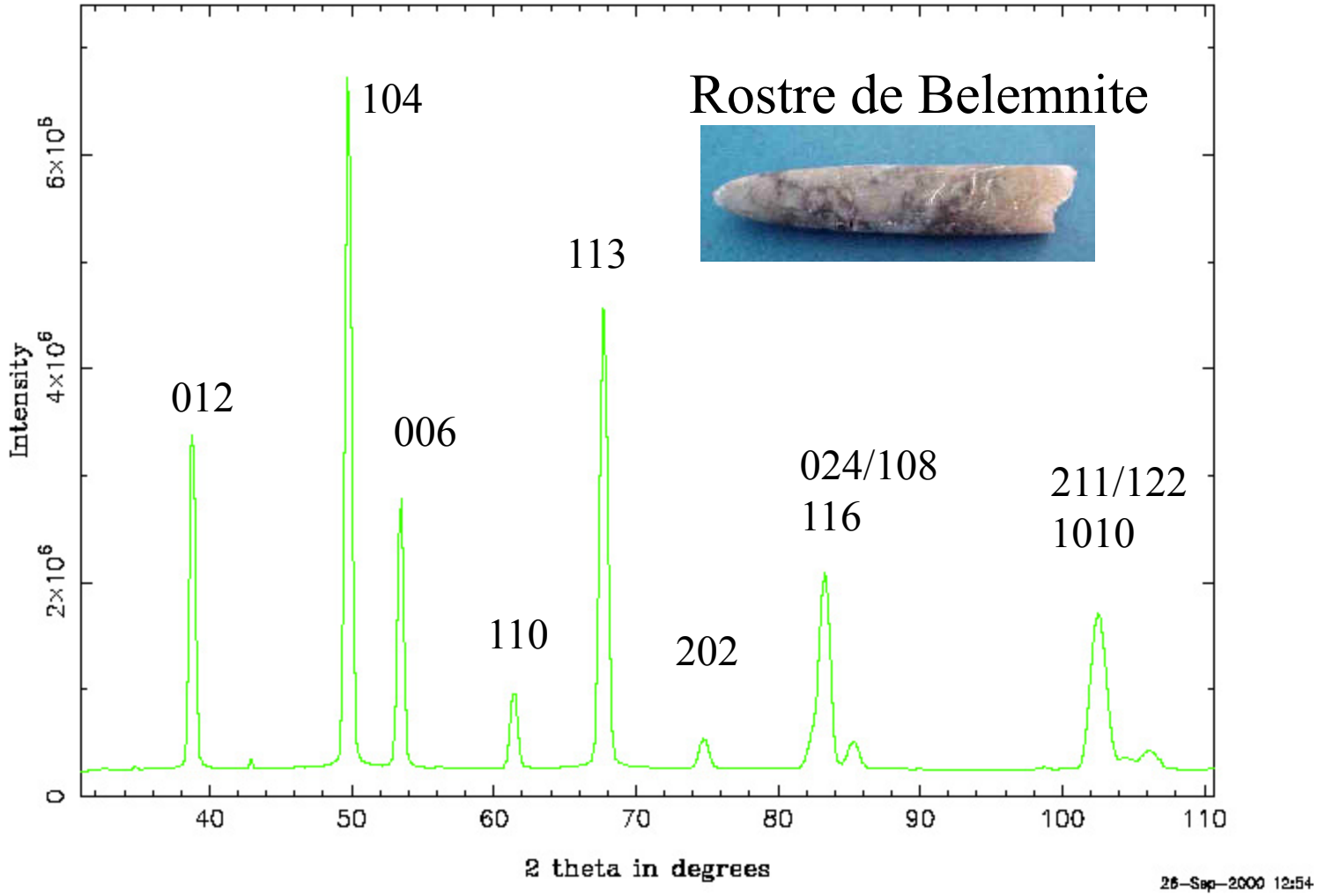
Diffraction de rayons X

Mytilus edulis

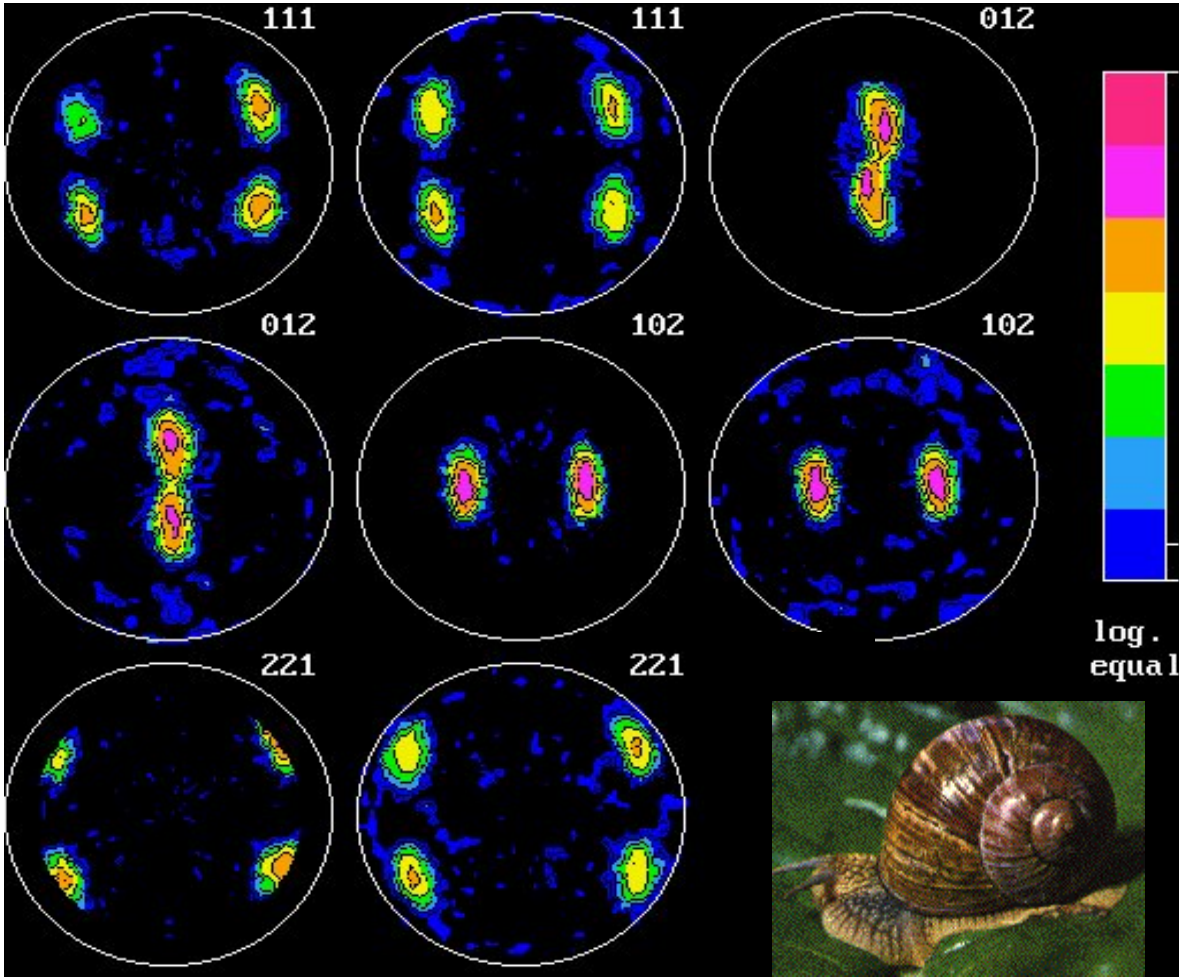
Crassostrea gigas



Diffraction de neutrons



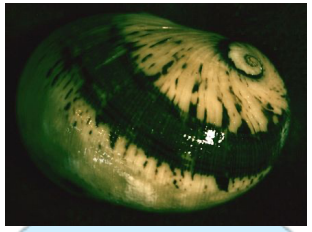
OD-reliability: *Helix pomatia* (Bourgogne)



Alignements types des axes **c**

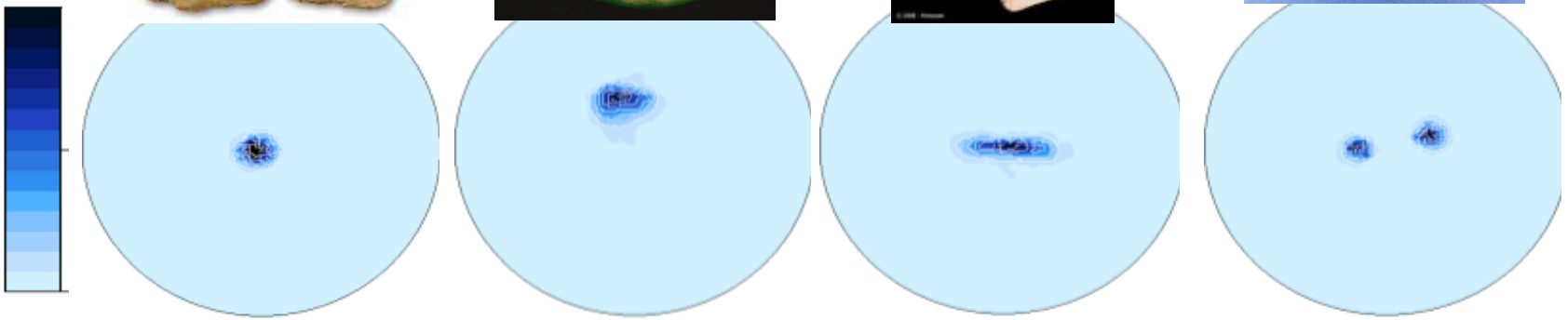
Pinctada maxima
ISN

Nerita polita
ICCL



Fragum fragum
ICCL

Cypraea testudinaria
ICCL

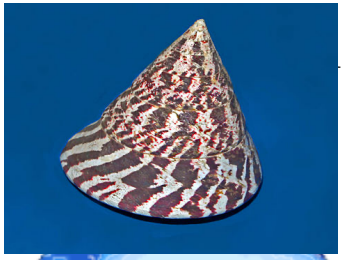


⊥ ∠ ∀ ∨

Alignements types des axes **a**

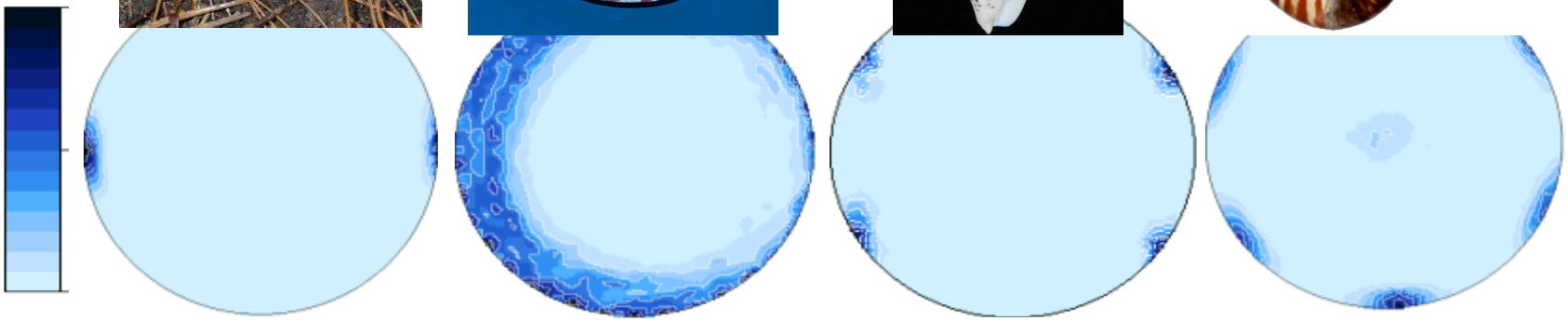
Helix pomatia
OCCL

Tectus niloticus
ICN



Conus leopardus
ICCL

Nautilus pompilius
ICN

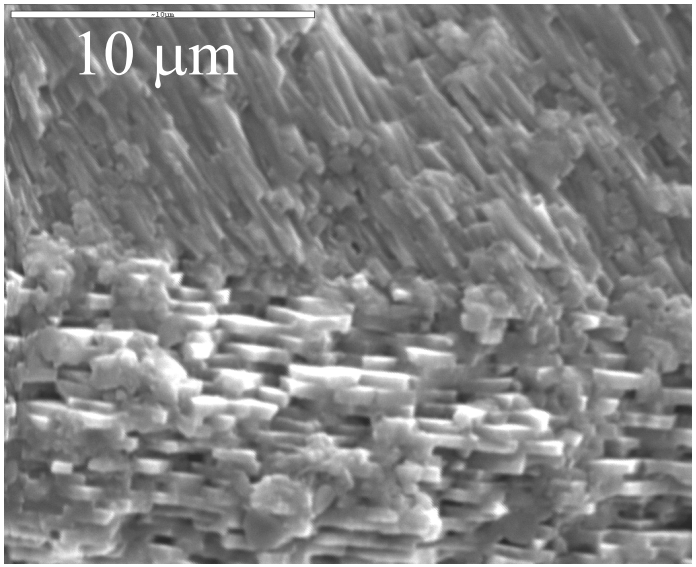


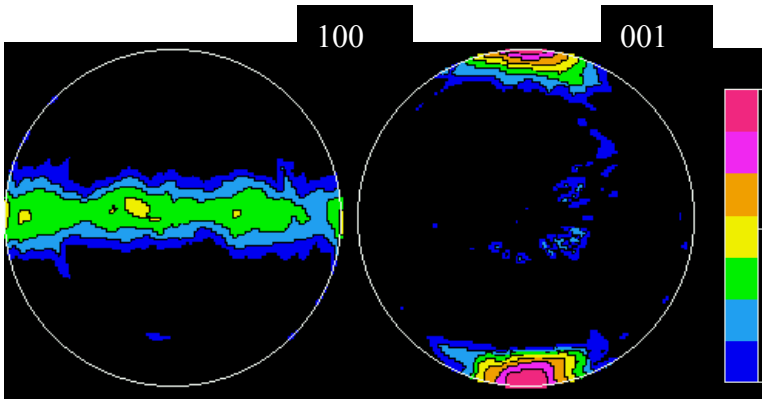
Chateigner, Hedegaard, Wenk, J. Struct. Geol. **22** (2000) 1723

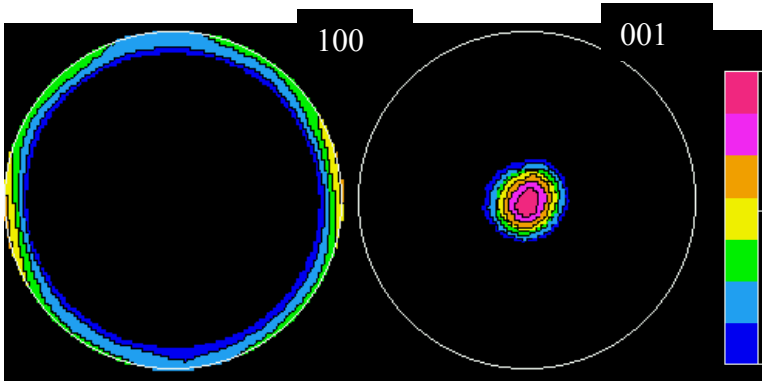
Microstructure versus texture

Bathymodiolus thermophilus (moule de -2400m)

$\langle \angle,90|\mathrm{OFC}|\mathrm{I}^{c,0} \rangle$







N

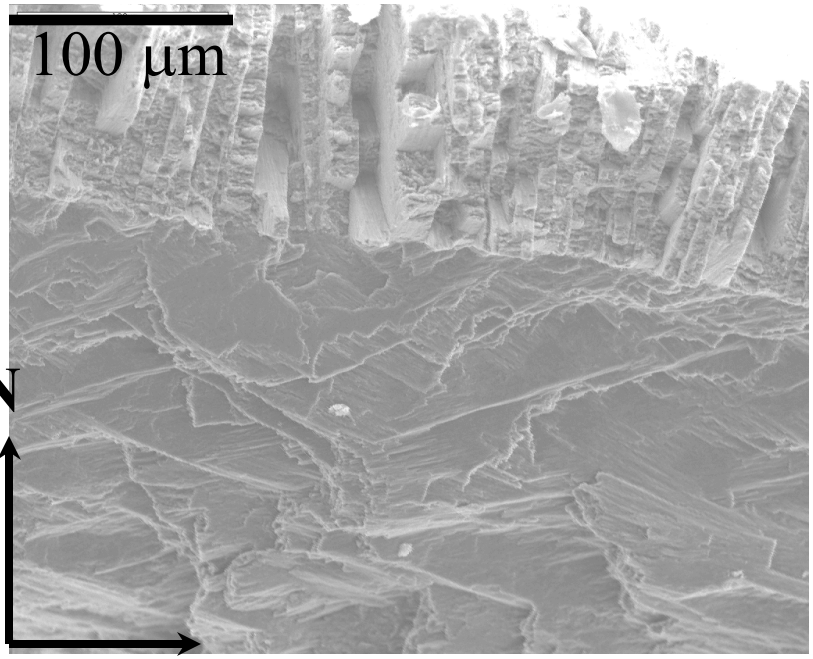
G

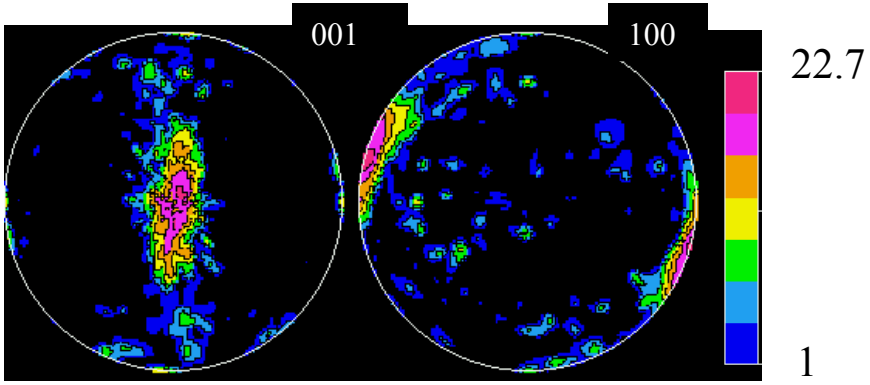
$\langle \perp|\mathrm{ISN}|*_{38}^{a,90} \rangle$

Microstructure versus texture

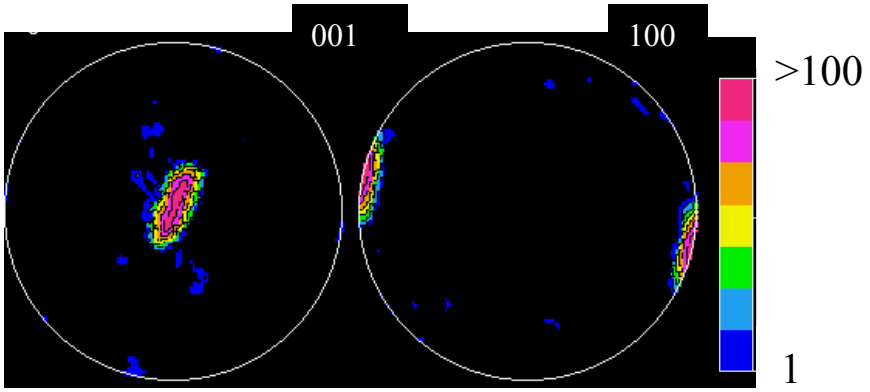
Euglandina rosea formes différentes, mêmes orientations !

$\langle \perp | \mathrm{ORCL} | \mathbf{I}^{a,75} \rangle$





no inter-mineral epitaxy



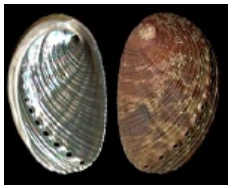
$\langle \perp | \mathrm{ICCL} | \mathbf{I}^{a,80} \rangle$

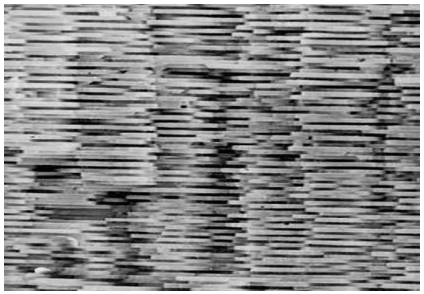
Deux grands types de Nacres

Gastéropodes

Nacre Colonnaire

Haliotis tuberculata (ormeau)

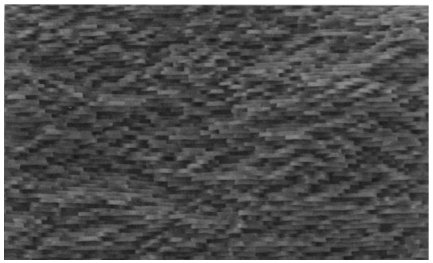




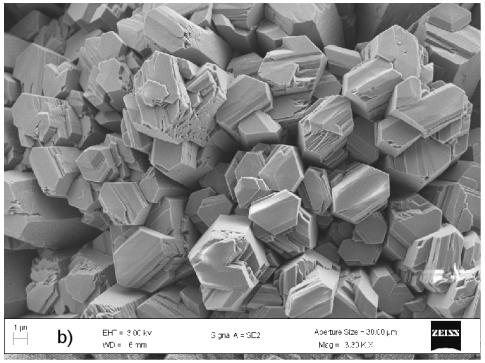
Bivalves

Nacre mur de briques

Pinctada maxima (huître perlière)



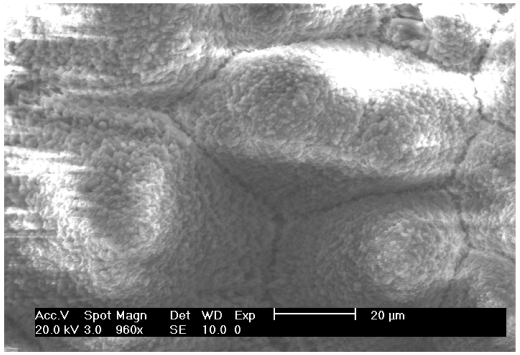
Couches électrodéposées $CaCO_3$/Ti-Al-V



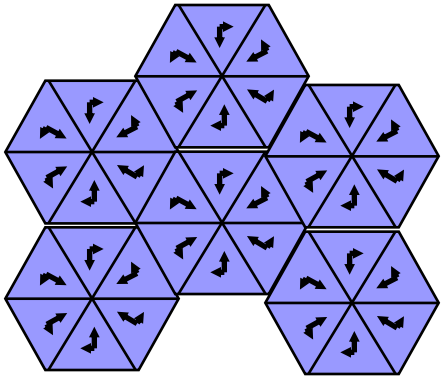
Electrolyte Inorganique

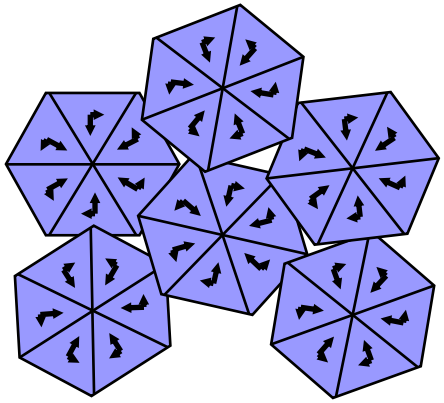
avec extrait non-polaire

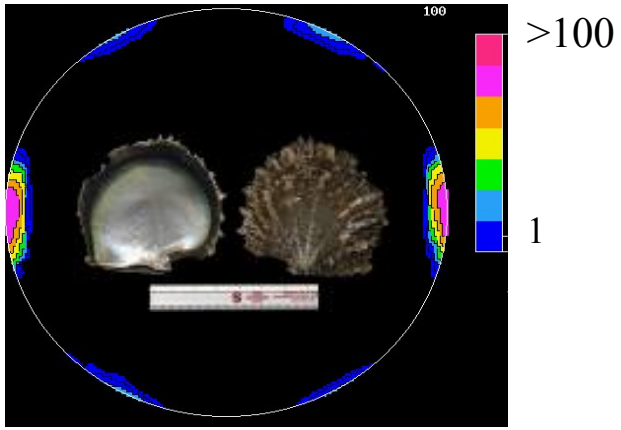
Pinctada maxima

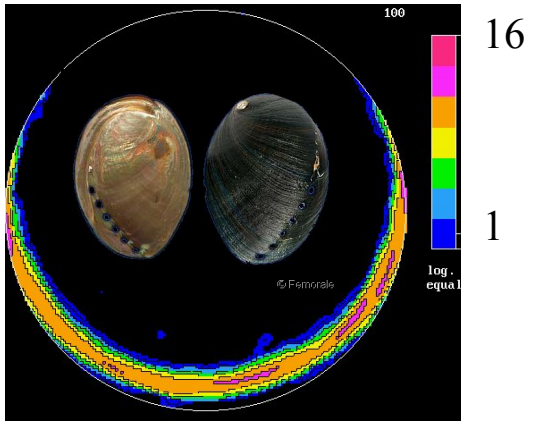


… that rearrange ...



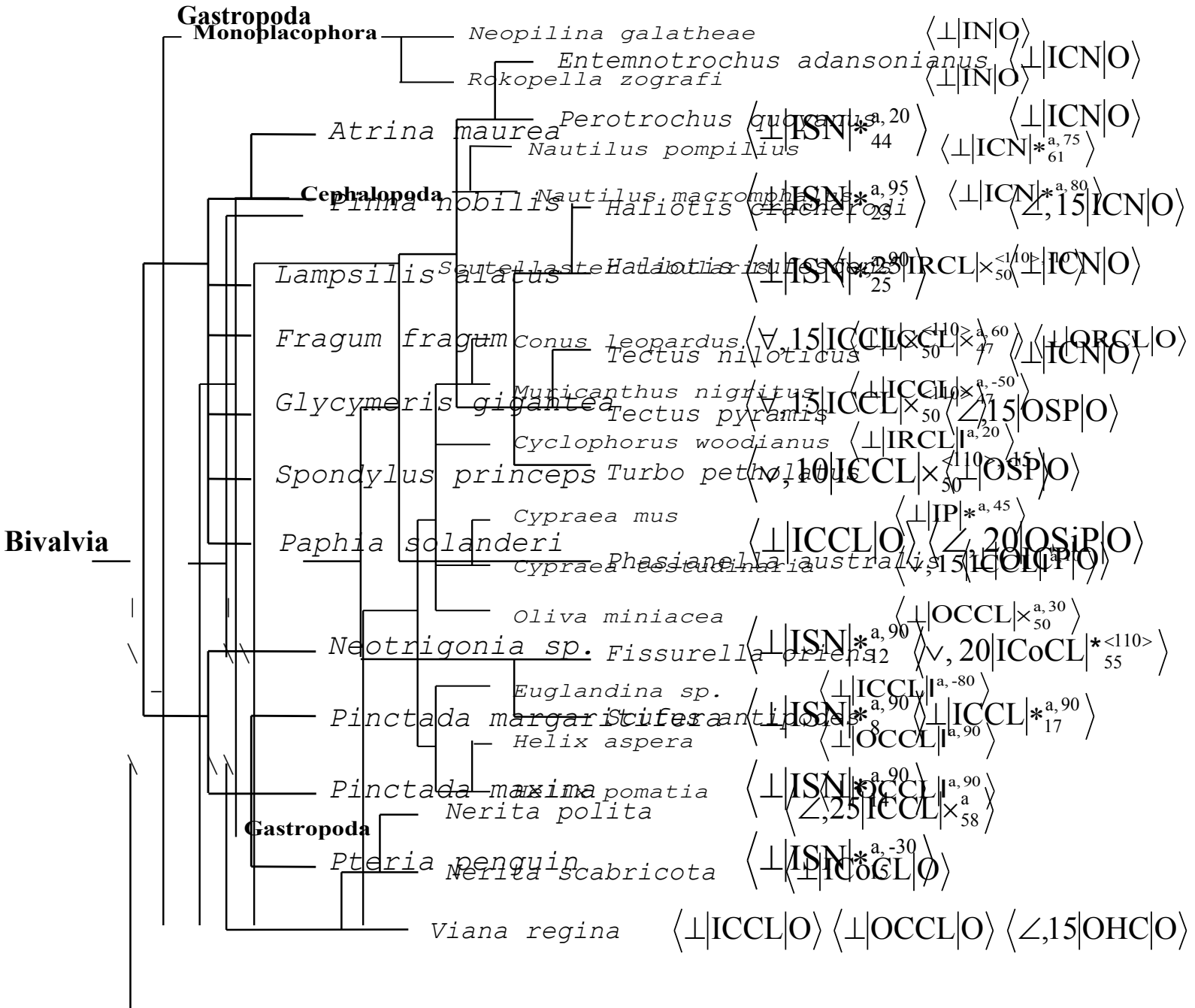






Pinctada margaritifera
(black pearl oyster)

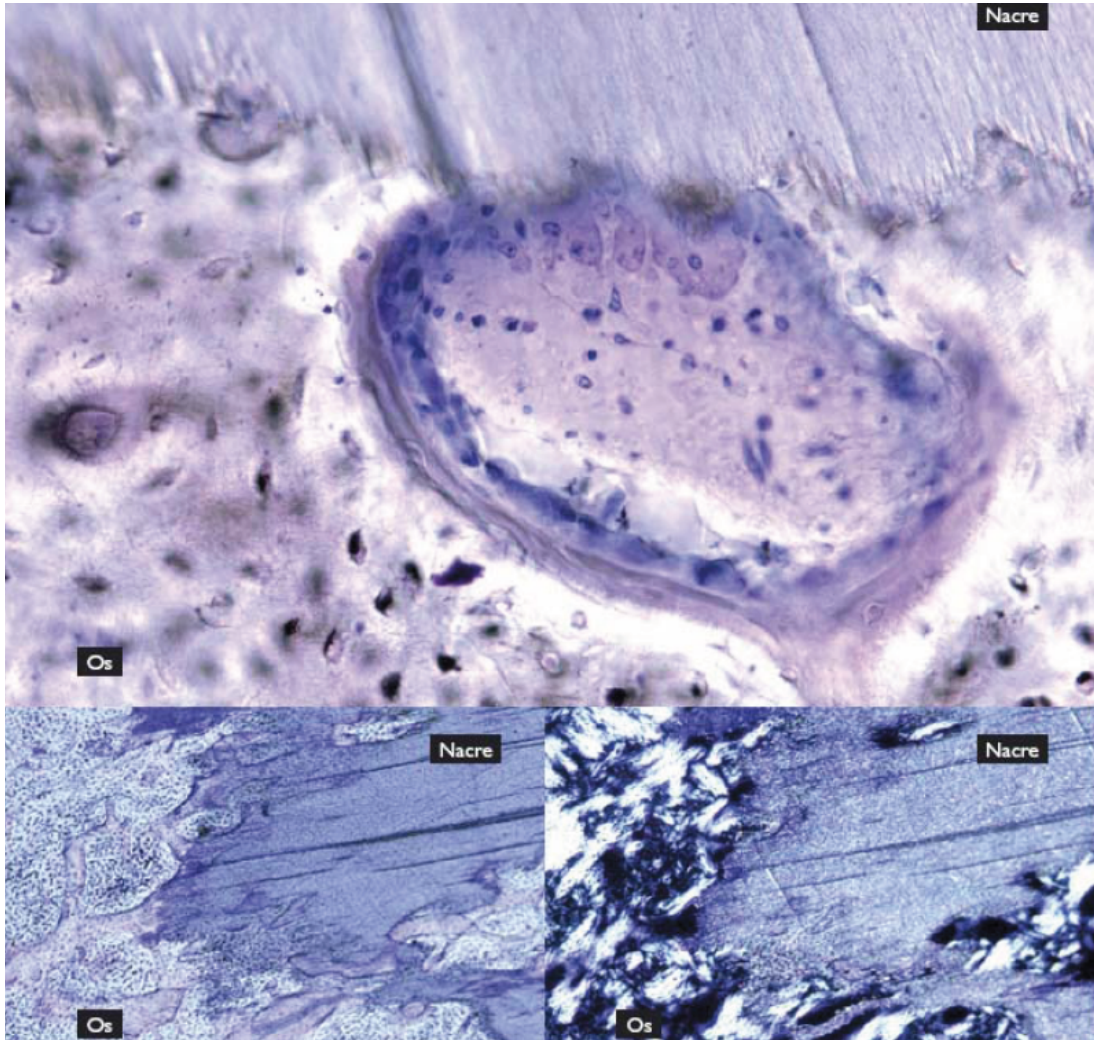
Haliotis cracherodi
(black abalone)


Gastropoda
Monoplacophora
Neopilina galatheae
Entemnotrochus adansonianus
Rokopella zografi
Atrina maurea
Perotrochus quoyanus
Nautilus pompilius
Cephalopoda
Pinna nobilis
Nautilus macromphalus
Haliotis gracherodi
Lampsilis alatus
Scutellastella tabularis
Haliotis iris
Fragum fragum
Conus leopardus
Tectus niloticus
Glycymeris gigantea
Muricanthus nigritus
Tectus pyramis
Cyclophorus woodianus
Spondylus princeps
Turbo petholatus
Cypraea mus
Bivalvia
Paphia solanderi
Phasianella australis
Cypraea testudinaria
Oliva miniacea
Neotrigonia sp.
Fissurella crenulata
Euglandina sp.
Pinctada margaritifera
Strophocheilus antipodes
Helix aspera
Pinctada maxima
Haliotis pomatia
Nerita polita
Gastropoda
Pteria penguin
Nerita scabricota
Viana regina

- 4000 av. JC
cranes maya, Honduras

Amadéo Bobbio (1972) *Bull. Historical Dentology*

Evelyne Lopez, MNHN, Paris

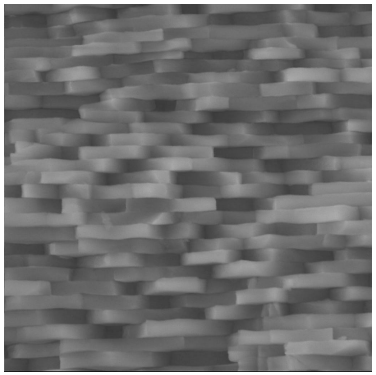


Stimulation des cellules osseuses à l'interface nacre/os

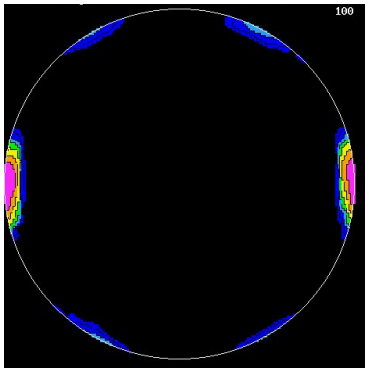
Pénétration d'os néo-formé dans la nacre

Evelyne Lopez *et al.* (1992) *Tissue & Cell*

Pinctada margaritifera, P. maxima and *Pinna nobilis* nacres: Bio-compatible and osteo-inductive for human osteoblasts (E. Lopez (MNHN, Paris)



Bivalvia



P. Margaritifera

Atrina maurea $\langle \perp | \mathrm{ISN} | *_{44}^{a,20} \rangle$

Pinna nobilis $\langle \perp | \mathrm{ISN} | *_{25}^{a,95} \rangle$

Lampsilis alatus $\langle \perp | \mathrm{ISN} | *_{25}^{a,90} \rangle$

Fragum fragum $\langle \forall, 15 | \mathrm{ICCL} | \times_{50}^{<110>} \rangle$

Glycymeris gigantea $\langle \forall, 15 | \mathrm{ICCL} | \times_{50}^{<110>} \rangle$

Spondylus princeps $\langle \vee, 10 | \mathrm{ICCL} | \times_{50}^{<110>,-15} \rangle$

Paphia solanderi $\langle \perp | \mathrm{ICCL} | \mathrm{O} \rangle \langle \angle, 20 | \mathrm{OSiP} | \mathrm{O} \rangle$

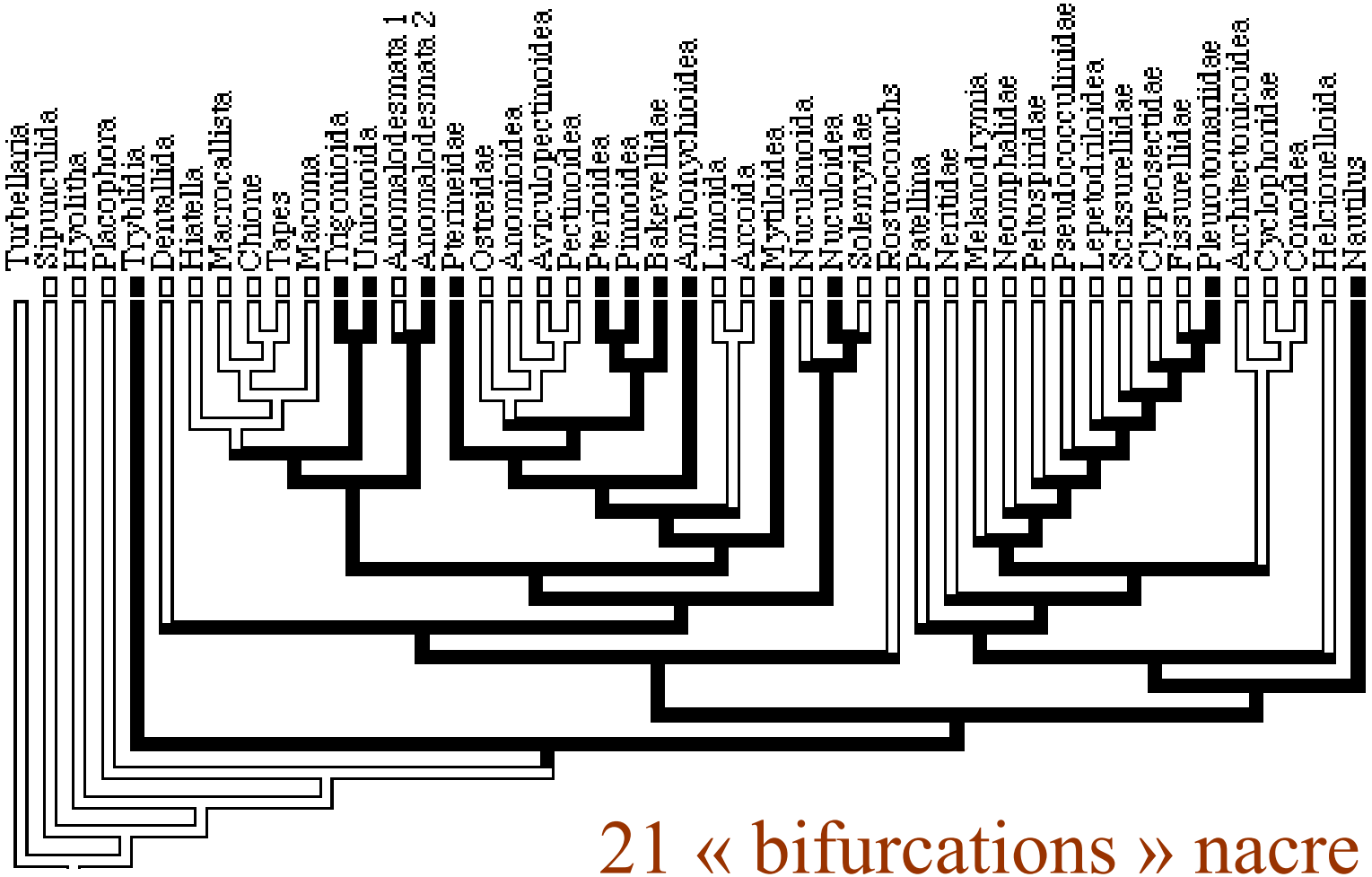
Neotrigonia sp. $\langle \perp | \mathrm{ISN} | *_{12}^{a,90} \rangle$

Pinctada margaritifera $\langle \perp | \mathrm{ISN} | *_{8}^{a,90} \rangle$

Pinctada maxima $\langle \perp | \mathrm{ISN} | *_{14}^{a,90} \rangle$

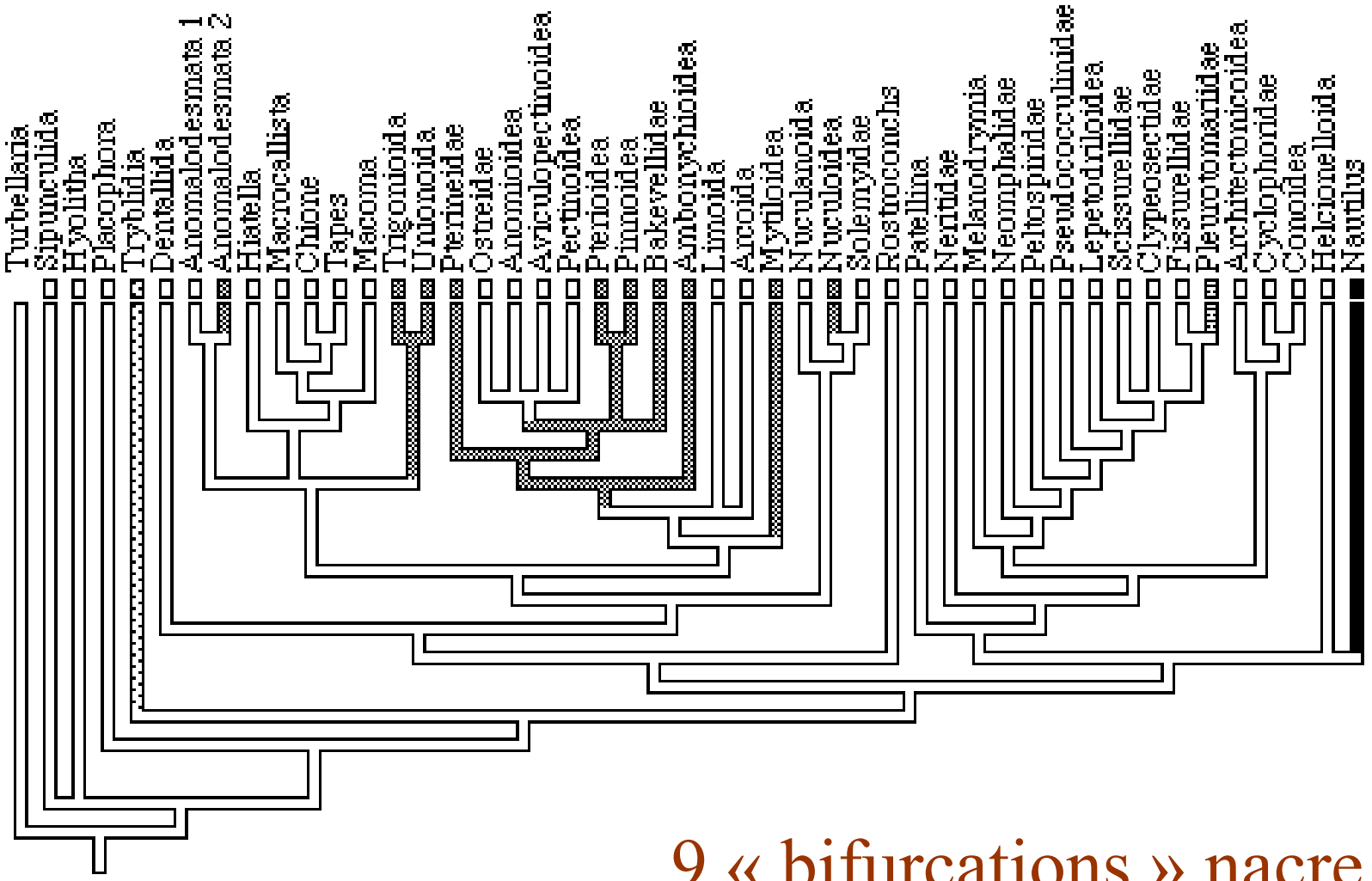
Pteria penguin $\langle \perp | \mathrm{ISN} | *_{15}^{a,-30} \rangle$

cladistique: nacre = ancestrale (Carter & Clarck, 1985)



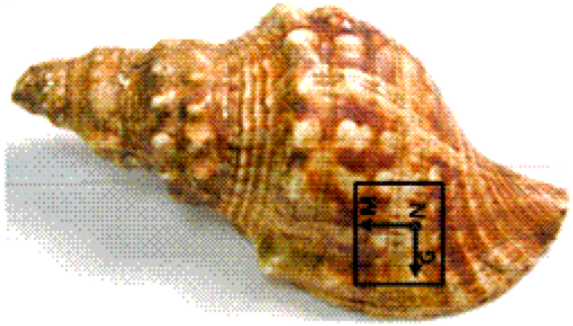
21 « bifurcations » nacre

nacre non ancestrale: plus parsimonieux



9 « bifurcations » nacre

Des propriétés mécaniques exceptionnelles, optimisées !

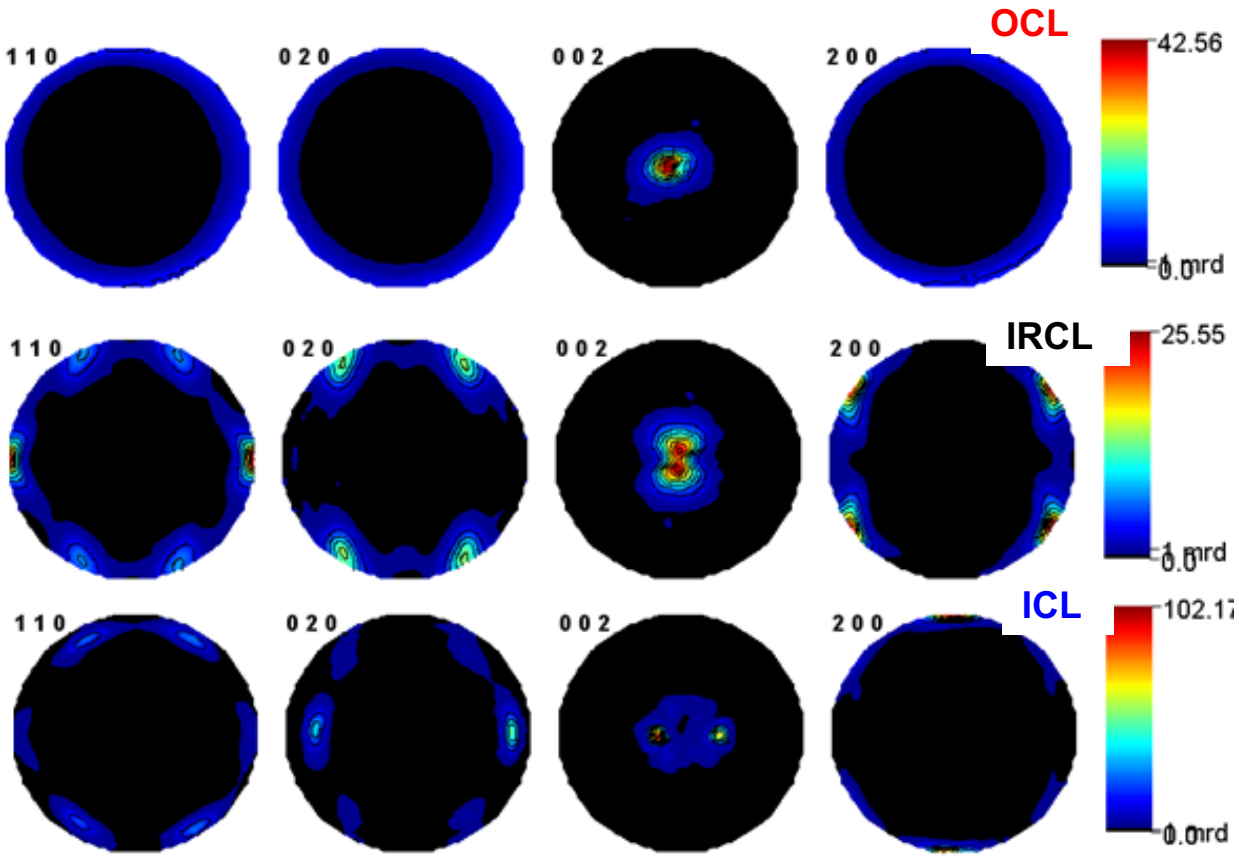


Charonia lampas lampas

OCL : Outer Comarginal Crossed Lamellae : lamellae plane // M

IRCL : Intermediate Radial Crossed Lamellae : lamellae plane ⊥ M

ICCL : Inner Irregular Complex Crossed Lamellae



Fiber texture: $\vec{c}$ // N

Split of $\vec{c}$ axes around N + two contributions // (G,N) plane.

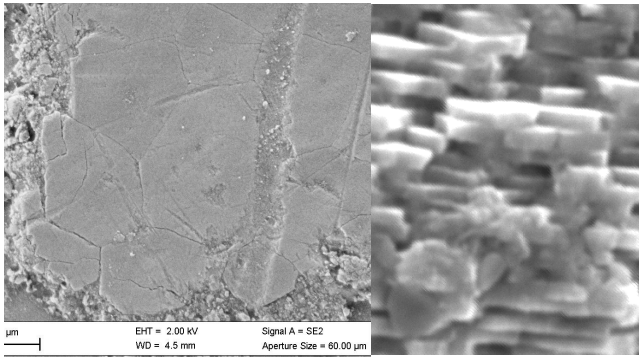
Split of $\vec{c}$ axes from N + two contributions // (M,N) plane.

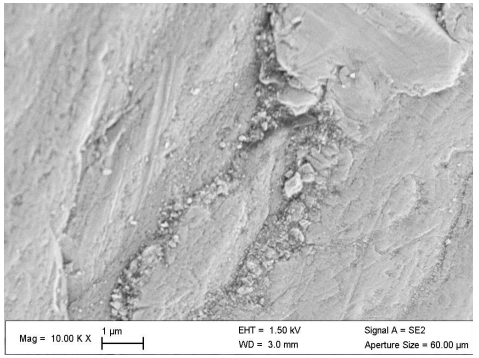
Ouhenia et al., *J. Struct. Biol.* **163** (2008)

Elastic stiffnesses

Single crystal	160	37.3 87.2	1.7 15.7 84.8	41.2	25.6	42.7
ICCL	96.5	31.6 139	13.7 9.5 87.8	29.8	36.6	40.2
RCL	130.1	32.6 103.3	10.3 14.1 84.5	36.3	31.1	40.5
OCL	111.1	32.9 119	13.2 11.8 84.8	32.8	34.6	40.9

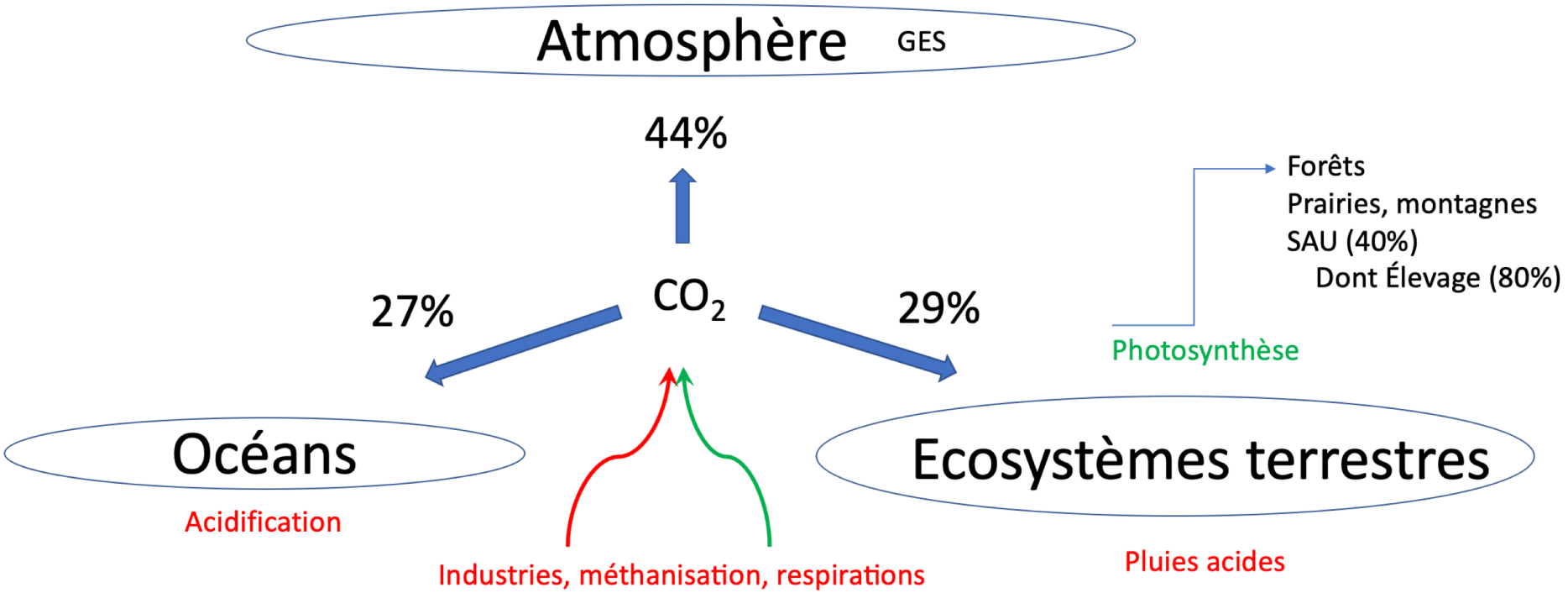
Hyriopsis cumingi (moule d'eau douce), Chine



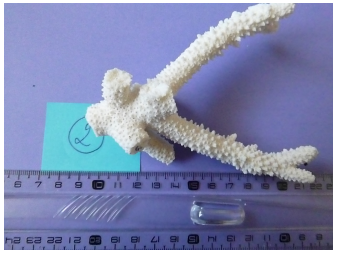


Nacre mur de brique (aragonite)

défauts structuraux (vaterite)

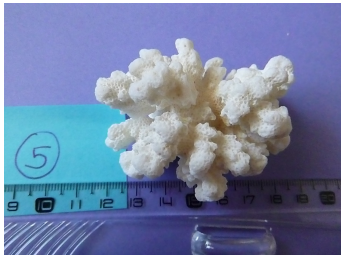

Atmosphère
GES
44%
CO_2
27%
29%
Forêts
Prairies, montagnes
SAU (40%)
Dont Élevage (80%)
Photosynthèse
Océans
Acidification
Ecosystèmes terrestres
Pluies acides
Industries, méthanisation, respirations

ET chez les coraux (Cnidaires) ?



Seriatopora

Millepora

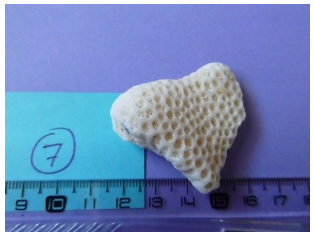


Acropora

Phaceloida

Invariablement de l'aragonite
Sauf certains fossils !

Fossilized sp.



Stylocoeniella

Turbinaria

Fungia

Lobophyllia

Cerioda

Pourquoi pas les aider ?

Caractéristiques du matériau

Durable et auto-cicatrisant

Le **Géocorail®** se forme au fil du temps et se restaure de lui-même en maintenant le dispositif actif.

Ecologique

Le **Géocorail®** fixe des éléments naturellement présents dans l'eau de mer, sans apports extérieurs et sans aucun rejet

Mise en œuvre sans moyen lourd

Produit directement sur site, le **Géocorail®** ne nécessite qu'un faible champ électrique sans danger pour les personnes (Tension V < Norme C15100)

Esthétique

L'agrégation des grains, graviers et débris coquilliers présents dans le milieu conserve formes et aspects à l'état naturel sans altérations

Epaisseur et caractéristiques mécaniques intéressantes

Evoluant dans le temps : plusieurs dizaine de centimètres

199x, Bloc de Géocorail®,
Plage de Sauzon (Belle-Ile-en-Mer)
Tapis de rétention de sable

2002, Bloc de Géocorail®,
Plage de la cible (Saint-Martin de Ré)
Démonstration liaison épi rocheux – plage sablonneuse

2005, Port des Minimes (plateforme exp.), M. Jeannin
Laboratoire LASIE (La Rochelle)
Consolidation de la falaises des Minimes

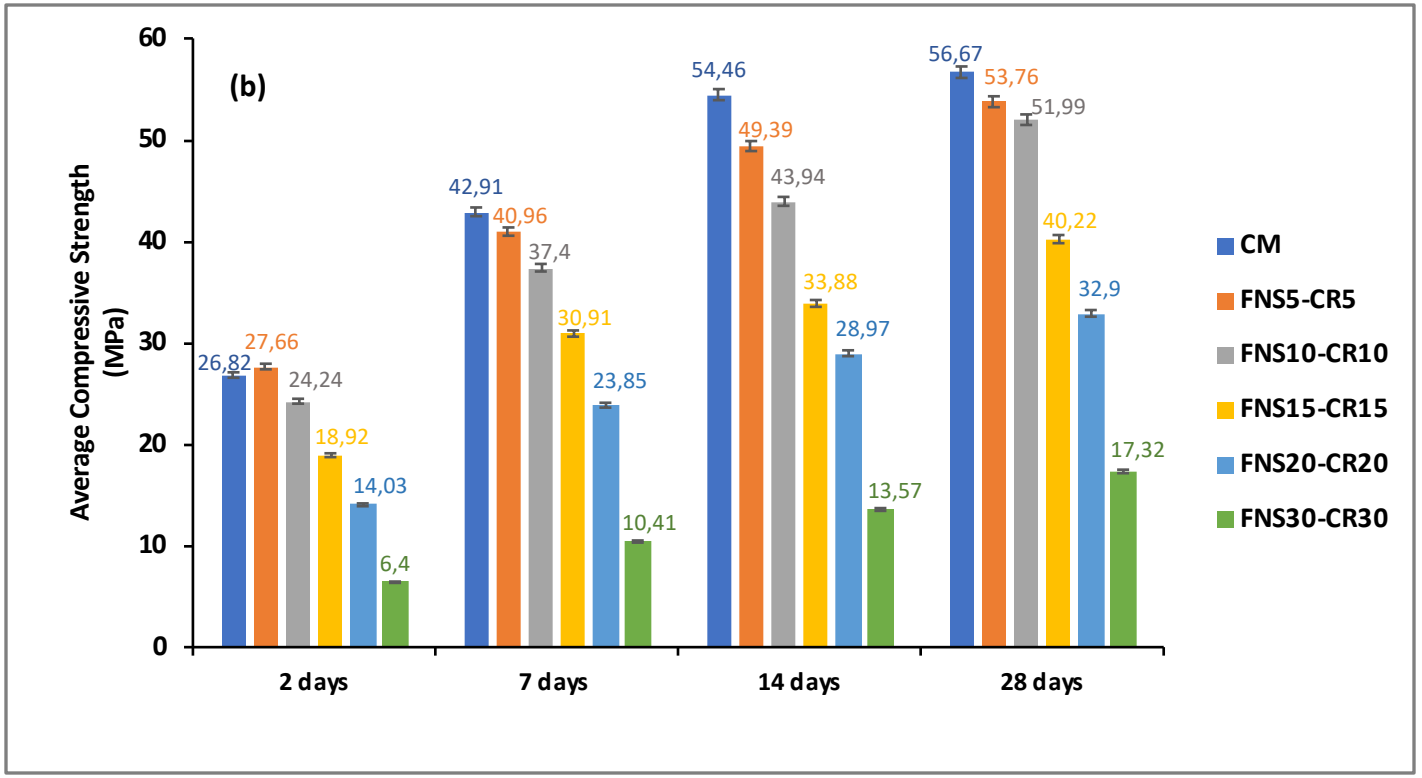
201x, Station Marine Luc-sur-Mer, O. Gil
Laboratoire ABTE (Caen)

Thèses de A. Zanibelatto, C. Carré, Postdoc de D. Nguyen)

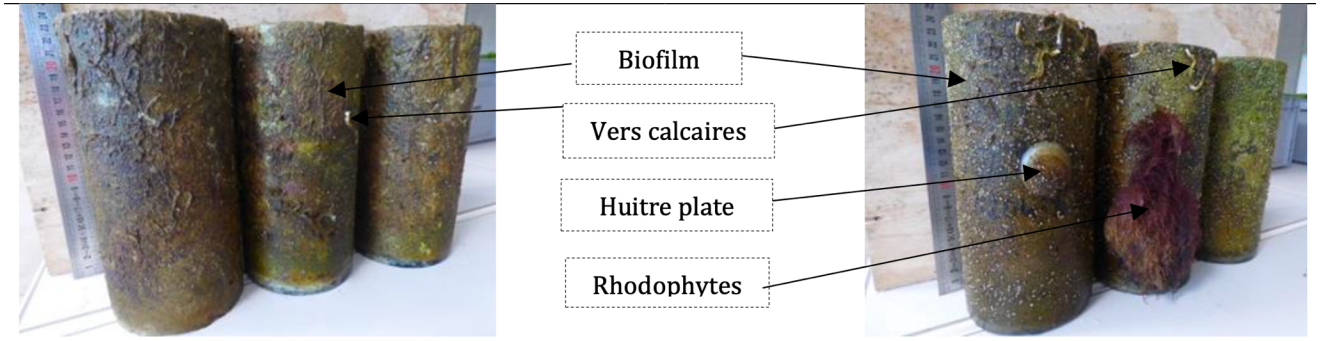
Géocorail formé en pied de falaise

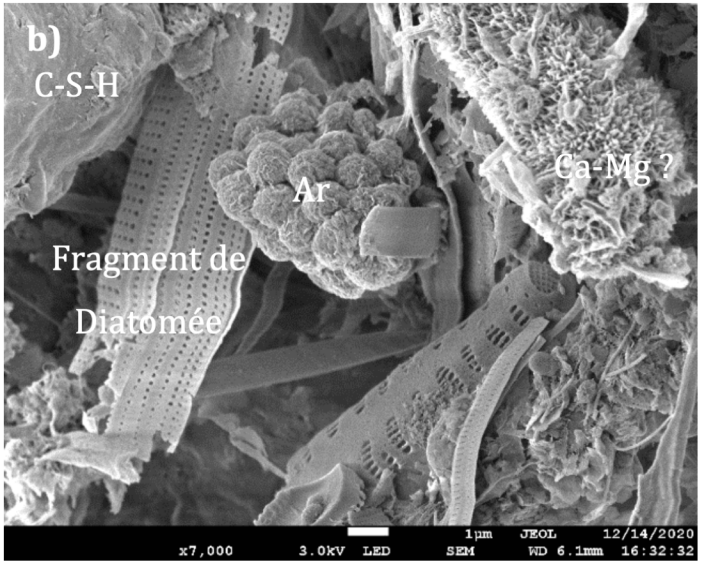
2014-2018: ANR EcoCorail (M. Jeannin, LASIE)
Angoulins-sur-Mer: *Restauration d'endiguement*
Luc-sur-Mer: *Aquarium du CREC*
Nouméa: *Aquarium des Lagons*
Wallis-et-Futuna: *Plage*
Châtelaillon: *Plage*
Géocorail®: Fos-sur-Mer

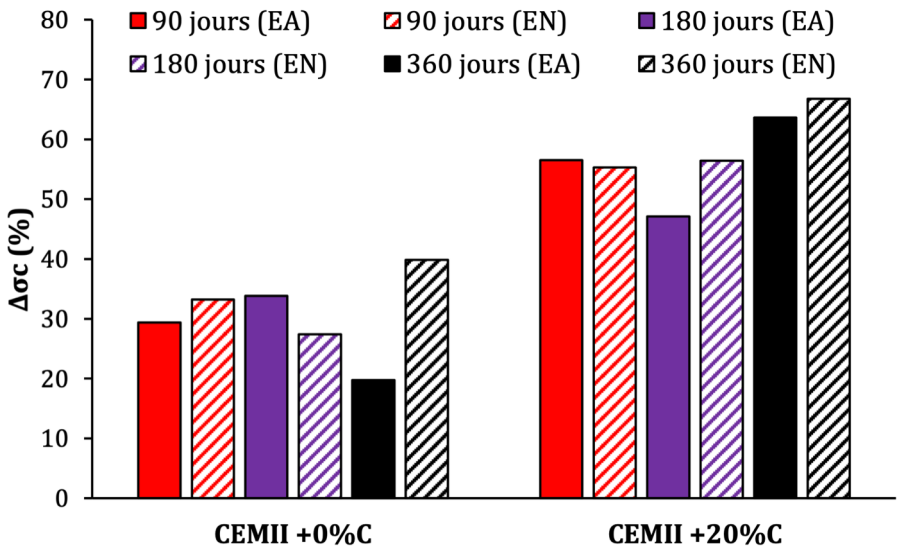
Aider à capter CO_2 tout en recyclant les déchets miniers et coquilliers ?



Incorporation de scories et de *Crepidula fornicata* (thèse M. Bouasria, ESITC Caen)







Néofaune algale: *Ostrea edulis* et biofilm de *Cylindrotheca closterium* (Thèse M. Georges, ESITC Caen)

Réflexion globale: Transition Energétique maintenant ?

Raréfaction des ressources
Raréfaction de l'énergie
Démographie croissante

Recul du Permafrost
Fontes calottes glaciaires

Démographie
Education
Modération
Optimisation

DEMO

GES : +4-7°C en 2100

Réduction des surfaces habitables et cultivables

Migrations de masse, famines, conflits

Remerciements

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Geocorail®; MARVEL expedition (1997); HOPE expedition (1999); EC: ESQUI, SOLSA; ANR: Ecocorail; Région Centre: SMAM